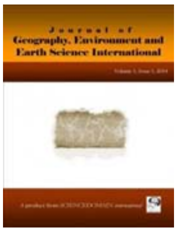

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Synoptic Conditions for Dry Winds in August 2010 in Ukraine

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Authors' contributions

This work was carried out in collaboration between all authors. All authors read and approved the final manuscript.

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ABSTRACT

Dry wind is a widespread dangerous phenomenon, which reduces the yield of crops in Ukraine. The aim of this study is to determine the conditions of the atmospheric circulation leading to the formation of dry winds in August 2010 and to determine the effect of these conditions on the distribution of dry winds in Ukraine during this period. Daily observations at 24 meteorological stations for the period from 31 July to 31 August 2010 were used, as the initial dataset. To define the location where the formation of initial dry wind air mass begins, backward trajectories for the previous movement patterns of air particles were constructed for period of a 120 hours (5 days) for the following heights: earth surface (0 m nominal), 1500 m and 3000 m for stations where the phenomenon was observed. During this period dry winds were observed in different parts of Ukraine, and the longest multi-day dry wind in period from 1995-2015 was observed at Mariupol station, from 31July 2010 to 20 August 2010, lasting 21 days. In first half of August 2010, air masses came from regions of northwestern Kazakhstan, the Ural Mountains, and the east and northeast of European Russia. After a blocking anticyclone over European Russia was dissipated, the baric field was reorganized, and territory of Ukraine was under the influence of the western air masses. After the development of an anticyclone over Central Europe at each heights, air masses

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came from the west from Central and Western European regions, and the North Atlantic.
The spread of dry winds over Ukraine occurred against the backdrop of the formation in the European sector of meridional of atmospheric circulation, with the development of a blocking process over European Russia. The development of dry conditions was facilitated by the stable, clear weather, without precipitation for a long time, as well as the descent of air masses in an anticyclone system, leading to their adiabatic heating.

Keywords: Dry wind; atmospheric circulation; blocking process; movement trajectories.

1. INTRODUCTION

In the summer of 2010, a period of anomalous heat was noted in the Northern Hemisphere. In Eastern Europe, the anomalous heat was accompanied by the development of drought conditions. This was caused by the formation of a blocking anticyclone over the European part of Russia. In June, after the invasion of the Arctic air mass on European Russia, an anticyclonic weather pattern was stabilized, and a drought occurred in the southern part of European Russia. Further, in late June - early July, there was a strengthening and an increase in the stationary anticyclone in the south of the European Russia. At many meteorological stations, pronounced anomalies of average monthly air temperatures were observed. In Ukraine, during this period, a drought was observed in the Steppe zone, and dry wind periods of different duration were observed throughout the territory [1,2]. Studies of atmospheric conditions in the summer of 2010 showed that at this time, large areas of positive air temperature anomalies and negative precipitation anomalies were observed over European Russia, and the eastern and northeastern regions of Ukraine [3]. The study [4] shows, that dry summer of 2010 was not preceded by dry spring, but was observed by more active blocking in Western Russia region during the spring seasons. This blocking event was more persistent and stronger than events preceding normal or wetter summers. During dry summer of 2010 strong blocking persisted through the season. In upper-level troposphere the strong tropospheric ridging dominated, and, generally, the dry summers in the Moscow region were associated with anticyclonic 500 hPa height anomalies centered over the poleward portion of the study region. The study [5] points to a natural cause of heat wave of 2010 in Russia. The authors show, that this event appears to be mainly due to internal atmospheric dynamical processes that produced and maintained an intense and long-lived blocking event, and regional land surface feedbacks caused increasing of the heat wave intensity. The authors concluded that it is very unlikely that warming of 2010 in Russia was connected with increasing greenhouse gas concentrations in atmosphere.

Dry wind is a widespread dangerous phenomenon, which reduces the yield of crops in Ukraine. The hot and dry winds inflict a special harm to spring grain crops, the active development of these crops falls during the spring-summer period. The dry wind can in a short time, significantly reduce or completely destroy future harvests. A study of the spatial and temporal distribution of dry winds, their meteorological characteristics, the dynamics of their development, and the circulation processes leading to their formation in Ukraine, is an actual problem, because dry winds, and droughts, occur almost every year during the vegetation period [6-9]. In Ukraine, at the present time, the phenomenon of dry wind is defined, according to [6], as simultaneous combination of the following meteorological conditions in at least in one observation: air temperature 25 °C and higher; wind speed at 10 m height is 5 m/s or more, and; the relative air humidity is 30% or lower.

The aim of this study is to determine the conditions of atmospheric circulation that led to the formation of dry winds in August 2010, and to determine the effect of these conditions on the distribution of dry winds in Ukraine during this period.

2. MATERIALS AND METHODS

2.1 Study Area

Ukraine is situated in the south-west of the East European Plain (Fig. 1). Its territory is 603.7 thousand km². In the south, Ukraine is

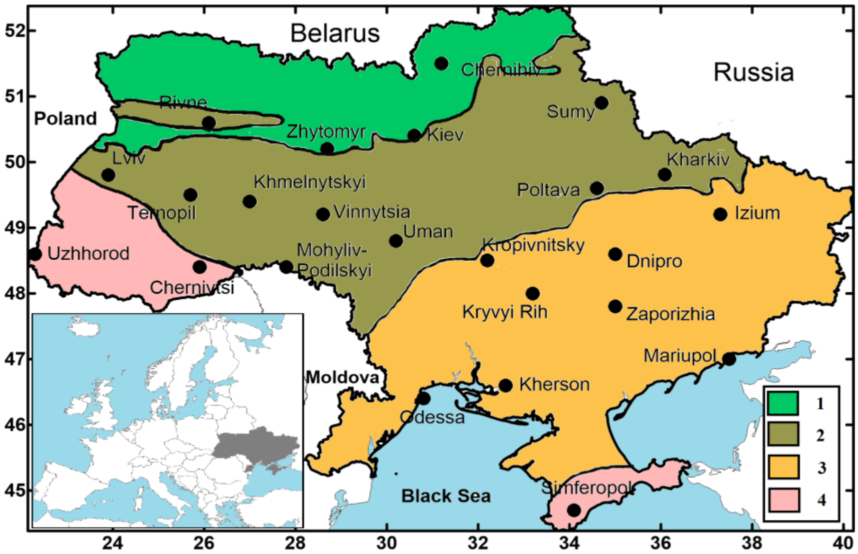


Fig. 1. A map of Ukraine with the location of meteorological stations, schematic location the territory of Ukraine on the map of Europe and schematic location the main agriclimatic zones of Ukraine: 1 – Polissya, 2 – Forest-steppe, 3 – Steppe, 4 – Mountains

bordered by the waters of the Azov and Black Seas. The major part of its area is flat, and only 5% is mountainous. Ukraine is located in zones of mixed forests, forest-steppe, and steppe of the East European Plain, and in two-mountain provinces − the Ukrainian Carpathians, and the Mountainous Crimea. Complex physicogeographical conditions cause a variety of climate, which changes from wetlands in the west of Polissya, to arid southern steppe areas.

The climate of the Ukraine can be described as a moderately continental climate, with hot, dry summers, and a relatively warm winter, and only on the southern coast of the Crimea does the climate have a subtropical, Mediterranean feel.

2.2 Data Source and Method

In order to study the spatial-temporal distribution of the dry winds, an analysis was made of the range of temperature and humidity at meteorological stations in Ukraine, located at the different agroclimatic zones (Fig. 1). Daily observations at 24 meteorological stations for the period from 31 July to 31 August 2010 was used as the initial dataset and has obtained from NOAA SATELLITE AND INFORMATION SERVICE [10]. To determine the dry wind, according to the specified criteria, the data for 8 sets of daily observations of air temperature, relative humidity, and wind speed were analyzed.

Synoptic weather maps and absolute topography maps of isobaric surface 500 hPa for 00 UTC for the period from 31 July 2010 to 31 August 2010 were used for the analysis. A synoptic weather map was obtained from the German Weather Service website [11], map AT-500 was obtained from website of the Air Resources Laboratory NOAA [12].

To quantify assessments of intensity and disturbance of atmospheric circulation, the index developed by Kats et al. [13] was used. For a given region, the change in the zonal flow of a mass of air depends only on the average pressure gradient in the sections of the meridians longitudes entering the zone, and meridianal mass flow from the average pressure gradient along the parallels (latitudes). Kats et al. [13], to estimate an index of the zonal I_z, and meridional I_m by calculating the average meridional and zonal gradients [13]. Calculation of the index was done in in the zone of 35-70° N in the Atlantic-Eurasian sector. Formulas for calculations of (1-3) are as follows:

$$I_z = \frac{1}{n}\sum_{i=1}^{n}\left(\frac{\Delta p}{\Delta \varphi}\right)_i, \quad (1)$$

$$I_m = \frac{1}{k}\sum_{j=1}^{k}\left(\frac{\Delta p}{\Delta \lambda \cos \varphi}\right)_j, \quad (2)$$

where *Δp* is difference of geopotentials in decameters at the boundaries of the zone for each of *i* selected meridians, and on the boundaries of the sector for each of the parallels; *Δφ* is the width of the zone in degrees of latitude;

$\Delta\lambda$ is sector width in degrees of longitude; n is the number of meridians; k is the number of parallels; $1/\cos\varphi$ is a multiplier for translating the arc length of the parallel in 1° increments of latitude φ to the length of the arc at the equator in increments of 1°.

The general index I_0 is defined as the following ratio:

$$I_0 = \frac{I_m}{I_z} \ , \tag{3}$$

As a criterion for estimating zonality or meridionality, the general index is the value $I_0 = 0.75$: if $I_0 \geq 0.75$, then the process is meridianal, if $I_0 < 0.75$, then the process is zonal. The source data for the calculation of indices by formulas (1-3) were the NCEP/NCAR reanalysis, daily fields of a geopotential surface height of 500 hPa.

An index called the European Continental Blocking Index of (ECBI) was proposed [14] to show the dynamic state of zonal flow associated with the emergence of a blocking process in the eastern part of the European continent. This is calculated in a domain that is bounded by the coordinates 10–80° west longitude, and 40–60° north latitude, using the following formula:

$$ECBI = \frac{\overline{u}_{pt}}{\overline{u}_{cl}} + 1 \, , \tag{4}$$

where $\overline{u}_{pt}$ is the current pendant value of the zonal wind velocity component, averaged over the region, at 300 hPa, and $\overline{u}_{cl}$ is the climatic value of the zonal wind velocity component, averaged over the area (the base period is from 1981 to 2010). The source data for the calculation of blocking index by formulas (4) were the fields of the NCEP/NCAR reanalysis, with a regular mesh interval of 2.5°, and a geopotential surface height of 500 hPa, taken in the domain that is bounded by the coordinates 10-80° E, and 25-70° N, as well as the fields of the zonal wind component u, at 300 hPa in the corresponding region.

To define the place where the formation of an air mass begins, which embodies dry wind properties in the territory of Ukraine, backward trajectories of the previous movement of air particles were constructed for the period of 120 hours (5 days) for the following heights: at the earth`s surface, 1500 m and 3000 m we used. For construction of the backward trajectories, the Air Resources Laboratory NOAA [15], HYSPLIT program. The trajectories were built for the following stations: on 1 August - Mariupol, Zaporozhye, Kharkov; on 14 August - Mariupol, Simferopol, Kropivnitsky; on 17 August - Mariupol, Simferopol, Chernigov; on 19 August - Simferopol, Kharkov, Mariupol; on 20 August - Odessa, Mariupol, Kherson; on 31 August - Simferopol, Dnieper, Kharkov.

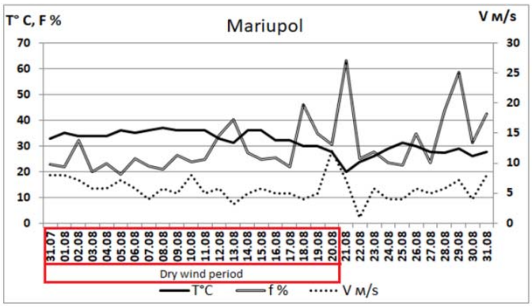
3. RESULTS AND DISCUSSION

During this time, dry winds were observed in different parts of Ukraine, and the longest multi-day dry wind during the period 1995-2015, was observed at Mariupol station from 31July 2010 to 20 August 2010, and lasted 21 days. The dry winds had the greatest distribution on the territory of Ukraine in the period 5-6 August 2010 (covering 11 stations), on 12 August (10 stations), and on 8 August and on 28 August (9 stations). Long dry wind periods were observed at Kropyvnytsky station (12 days), Kharkov station (9 days), and Simferopol station (8 days).

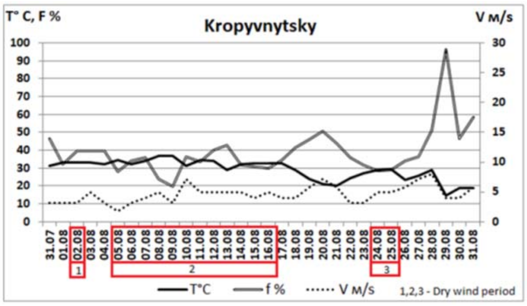
3.1 Meteorological Parameters in Periods of Dry Wind

An analysis of meteorological parameters at Mariupol station (Fig. 2a) showed that the maximum value of air temperature was 37.8° C (at 2:00 p.m. local time on 8 August and at 4:00 p.m. on 10-11 August). The minimum value of relative humidity was 15% (at 4:00 p.m. - 5:00 p.m. on 3 August and at 5:00 p.m. on 5 August). The maximum wind speed was 13 m/s (at 9:00 a.m. on 1 August).

At Kropyvnytsky station, multi-day dry winds periods were observed on 2 August, 5-16 August, and 24-25 August. An analysis of meteorological parameters (Fig. 2b) showed that the maximum of air temperature was 38.3°C (at 3:00 p.m. local time on 8-9 August). The minimum value of relative humidity was 14% (at 3:00 p.m. on 6 August), and the maximum wind speed was 9 m/s (at 3:00 p.m. on 13 August). The figure shows that at beginning of study period, on days without dry wind, the high temperatures were observed at this station, while the relative humidity and wind speed did not correspond to dry wind criteria. During the periods 17-23 August and 26-31 August, the absence of dry wind condition was due to high relative humidity.



(a)



(b)

Fig. 2. The air temperature, relative humidity and wind speed at 1:00 p.m. local time at (a) Mariupol and (b) Kropyvnytsky stations in period from 31 July to 31 August, 2010

3.2 Development of synoptic processes in period from 31 July 2010 to 31 August 2010

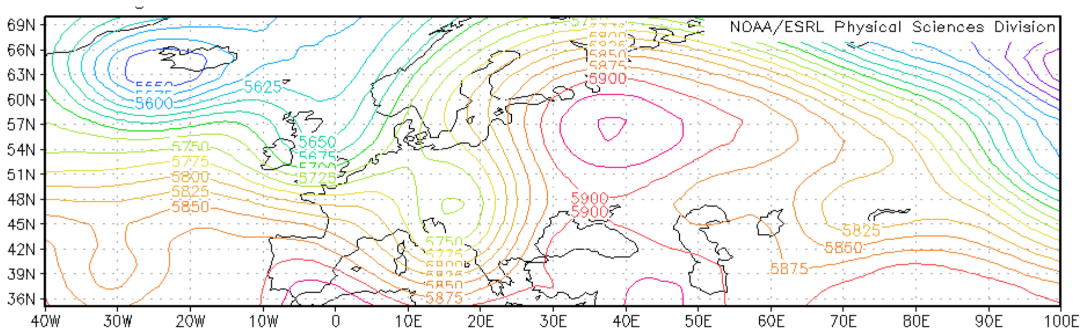
For determination of the atmospheric circulation type, the Katz circulation indices in the Atlantic-European sector were calculated. An analysis showed that during most of period the atmospheric circulation has zonal type (value of general index did not exceed 0.75). The meridional type of atmospheric circulation was established from 31 July to 1 August, on 5 August, 14-15 August and 21 August 2010.

Analysis of ECBI showed, that during period from 30 July to 18 August, the index had positive values (from 0.23 to 0.66), which indicates the presence of a blocking process in this region. In period from 19 August to 2 September, the ECBI had a negative values (from -0.16 to -0.38), which indicates the absence blocking process on these days.

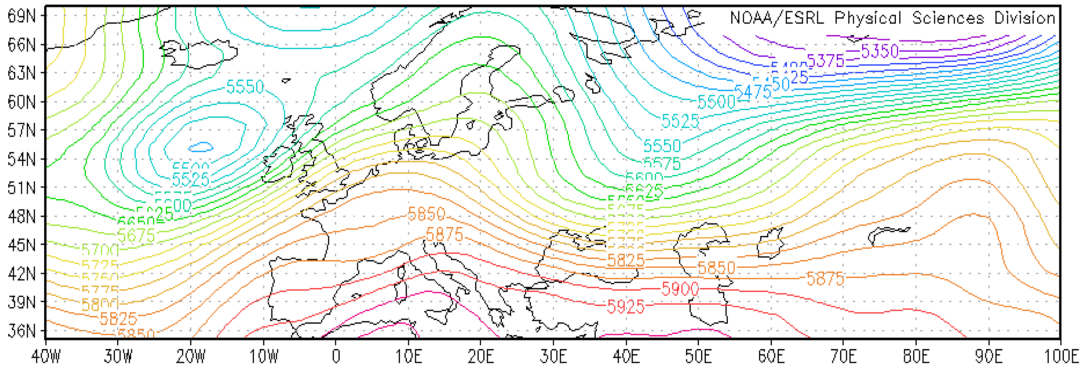
3.2.1 An upper-level baric field

The upper-level baric field during the period from 31 July to 16 August was characterized by the development of an extensive upper-level anticyclone over Eastern Europe, which reached its maximum development on 7 August. Over the Northern and Norwegian Seas, the area occupied by an upper-level cyclone was located, from which an extensive upper-level baric trough spread through Western and Central Europe. The second focus of cyclonic activity was observed over Western and Central Siberia. Between these upper-level centers were located the upper-level frontal zone.

The upper-level baric field from 1 August to 12 August (Fig. 3a) was characterized by the presence of an extensive blocking anticyclone, with its center over European Russia. On 17 August, this upper-level anticyclone over Eastern Europe was destroyed, and on the AT-500 map it was traced in the form of a strongly extended baric ridge, whose axis was oriented from the southeast to the northwest, and passed through the territory of Ukraine and the Baltic region. During the period 18-24 August, two areas of cyclonic circulation were observed in the upper-level baric field (Fig. 3b), one above the Norwegian Sea, the second above the Kara Sea. From these cyclonic formations in the southern direction two baric troughs descended, between which the upper-level baric ridge was located above Central and Eastern Europe. During the period 25-28 August, the upper-level baric field in the European sector acquired a quasi-zonal character.



(a)



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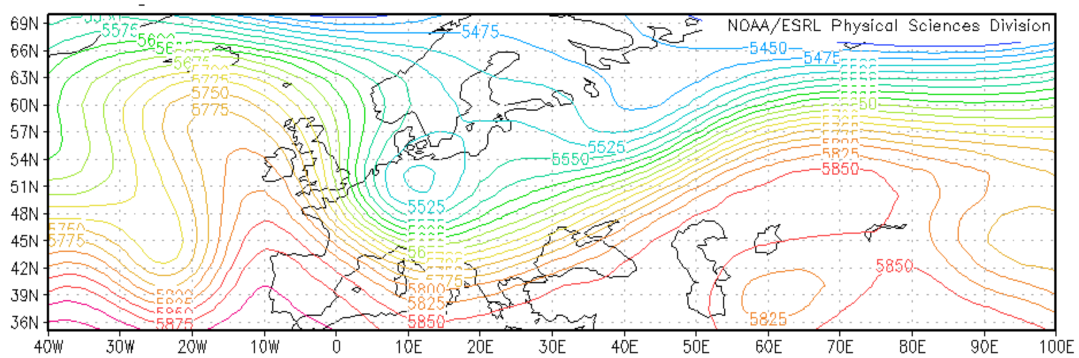


(c)

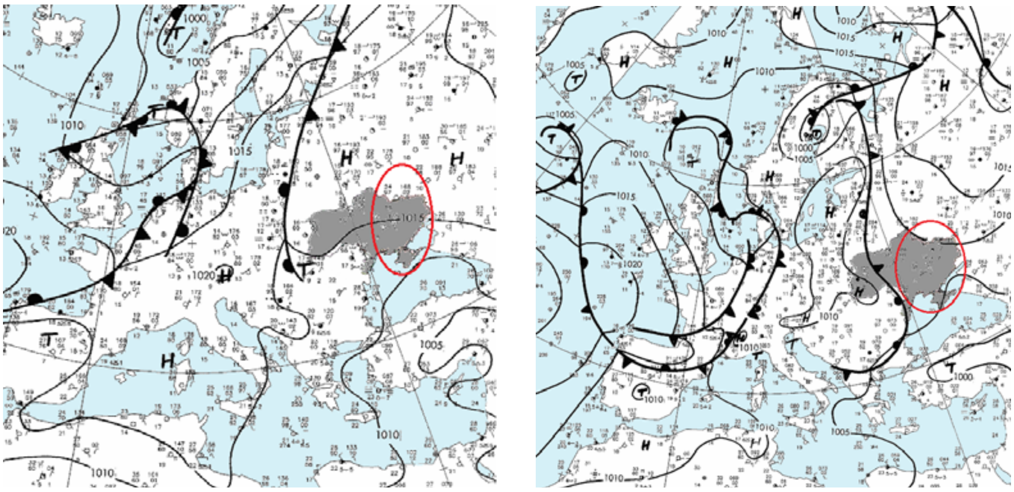
Fig. 3. The fields of geopotential height (meters) of the isobaric surface (500 hPa): (a) – 7 August 2010, (b) – 20 August 2010, (c) – 30 August 2010 [12]

On 29 August, the upper-level cyclone formed over the Norwegian Sea. It moved southward and has located on 31 August above Central Europe. The upper-level baric ridge was observed over the eastern part of the North Atlantic, it then shifted to Western Europe on 31 August. On 30 August, an upper-level anticyclone and a dipole-type block formed above the south Ural Mountains (Fig. 3c).

3.2.2 <u>Surface pressure field</u>

During the period from 31 July to 12 August, the synoptic situation at the earth`s surface was influenced by a series of cyclones over Northern Europe (Fig. 4). The territory of Central Europe, Western Europe, and European Russia was under the influence of a low-gradient baric field. During this period, Ukraine was under the influence of a low-gradient baric field of increased pressure, and clear weather without precipitation was observed on its territory. The dry winds on 31 July were noted at 2 stations located in the east and south-east of country. During the period 1-12 August, dry winds were recorded simultaneously at 5-11 stations located all over Ukraine, with the exception of the western and north-western regions.

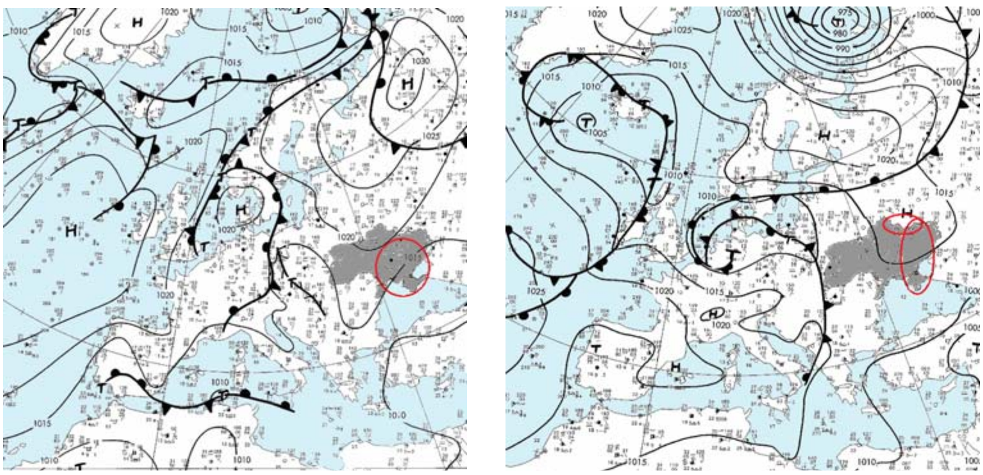
On 13 August, there was an intensification of anticyclone behavior over Eastern Europe, and its baric ridge stretched through the territory of Ukraine to the Balkan Peninsula. This anticyclone was a high baric formation, and was traced on the AT-500 map as a closed circulation. In central and north-eastern regions of Ukraine, this day had cloudy weather with clearing periods, punctuated by heavy rains and thunderstorms. Clear weather without precipitation was observed in the southern and western regions. The dry winds were noted at 8 stations. During the period 14-15 August, the weather conditions in Ukraine were formed under the influence of the baric ridge of anticyclone behavior over European Russia. In the central and eastern regions, cloudy weather without precipitation was noted. In the southern, western, and northern regions, clear weather without precipitation was observed. The dry winds were noted at 7 stations located in the Steppe zone of Ukraine.



(a) (b)

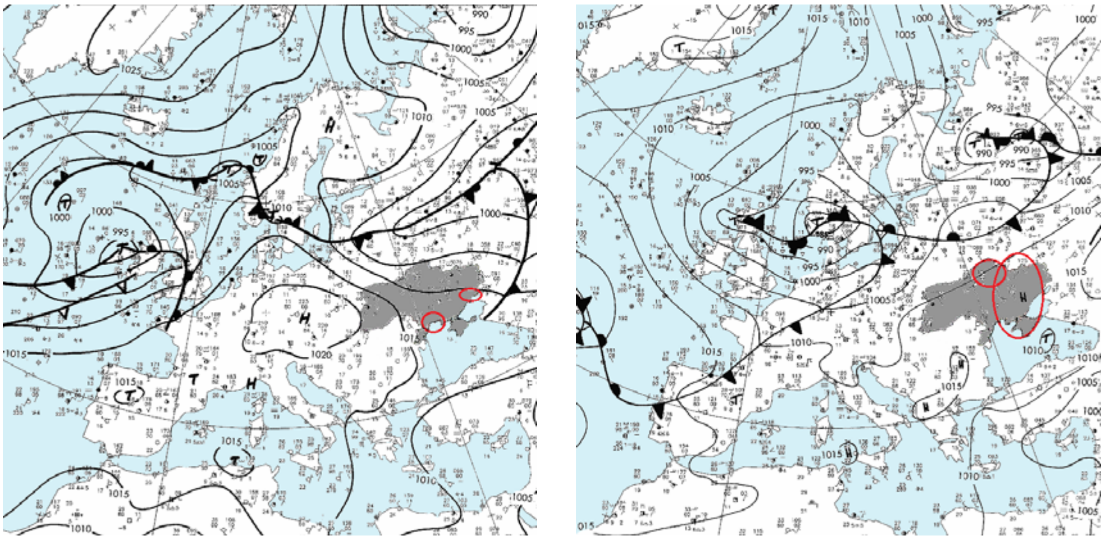
Fig. 4. A synoptic weather map (a) on 1 August 2010, (b) 5 August 2010 [11]
The area covered by the dry wind is schematically marked with a red circle

During the period 16-20 August, cyclonic activity was located over Northern Europe (Fig. 5). On 16 August, the anticyclone over European Russia was dissipated. The territory of Central and Eastern Europe was under the influence of a low-gradient baric field. During the period 16-17 August, Ukraine had clear weather without precipitation. The dry winds were noted at stations located in the Steppe zone of Ukraine. On 18 August, Ukraine's territory was under the influence of a low-gradient baric field in form of a saddle, with a hyperbolic point over the south-western part of country. This led to the establishment of clear weather without precipitation. The dry winds were noted at 4-6 stations located in the southern, eastern, and north-eastern regions of Ukraine. On 19 August, a cold atmospheric front passed through the territory of Ukraine. Its passing was accompanied by thunderstorms and torrential rains in the central and southern regions. During the period 19-21 August, a decrease in the number of dry winds was observed, and this phenomenon is noted at 1-5 stations located in the southern and eastern regions. On 20 August, an anti-cyclone over Central Europe was formed (Fig. 6a). On the southern branch of the polar front over the European Russia and Belarus, an extensive young cyclone was formed. The eastern regions of Ukraine were influenced by the rear of the cyclone over European Russia, the western regions were under the influence of the front part of anticyclone above Central Europe, and the southern regions were under the influence of a low-gradient baric field. Clear weather without precipitation was observed all over territory.



(a) (b)

Fig. 5. A synoptic weather map (a) on 14 August 2010, (b) 17 August 2010 [11]
The area covered by the dry wind is schematically marked with a red circle



(a) **(b)**

Fig. 6. A synoptic weather map (a) on 20 August 2010, (b) 24 August 2010 [11]
The area covered by the dry wind is schematically marked with a red circle

During the period 21-22 August, there was a strengthening of an anticyclone over Central Europe, and its center shifted by 500 km in an easterly direction. The territory of European Russia was occupied by a zone of cyclonic activity. The mutual arrangement of these baric formations led to the invasion of cold air along the western periphery of the cyclone and the eastern periphery of anticyclone, as a result, a cold atmospheric front passed through territory of Ukraine. It led to the establishment of cloudy weather, with precipitation, in the central and northern regions.

During the period 23-25 August, the territory of Ukraine was in a low-gradient baric field of increased pressure (Fig. 6b). The territory experienced clear weather without precipitation, which led to intensive heating of the air. During the period 24-25 August, a marked increase in the number of stations covered by dry wind was observed simultaneously at 8-9 stations, located in the southern, eastern, and north-eastern regions of Ukraine.

During the period 26-29 August, a series of cyclones was located over Northern Europe (Fig. 7a), which moved south-eastward, crossing the territory of Poland to European Russia. As a result, a cold front passed through the territory of Ukraine. The passage of the front led to a decrease in air temperature in the western and north-western parts of the country. During the period 26-27 August, Ukraine noted cloudy weather, with some places observing torrential rains. The dry winds were observed at 5-6 stations located in the south-south-eastern regions. On 28 August, in the central, northern, and north-western regions of Ukraine, cloudy weather with clearing sky, in the south of country, and clear weather without precipitation was noted through the territory. The dry winds on this day were noted at two meteorological stations − Simferopol and Izyum. On 29 August, cloudy weather was noted throughout the territory, except for the Crimea, which was in a zone in front of observed heavy rains and thunderstorms. Dry winds noted only at Simferopol, where there was clear weather without precipitation.

During the period 30-31 August, an extensive anticyclone formed over Great Britain (Fig. 7b). The ridge extended from it to European Russia. Ukraine was under the influence of a low-gradient baric field. On its territory was clear weather without precipitation. The dry winds were observed at 1-3 stations located in the southern and eastern regions of the country.

3.3 A Trajectories of Air Particles Movement

The analysis showed that from 1 August to 16 August, during the period when the development of the eastern type of processes was observed (Fig. 8a; b), at stations where dry winds were observed, air masses came from regions of northwestern Kazakhstan, the Ural Mountains, and the east and northeast of European Russia. Further, on 17 August, after a blocking

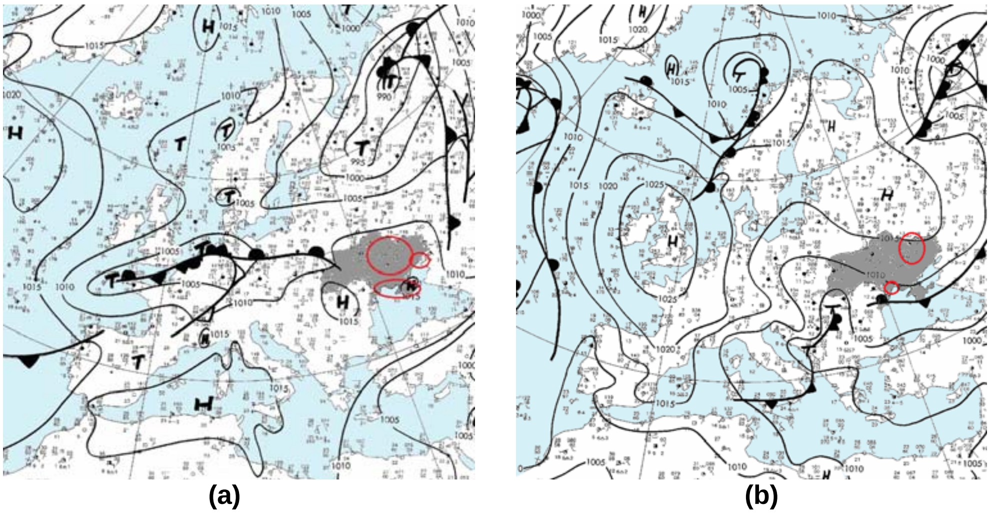


Fig. 7. A synoptic weather map (a) on 27 August 2010, (b) 31 August 2010 [11]
The area covered by the dry wind is schematically marked with a red circle

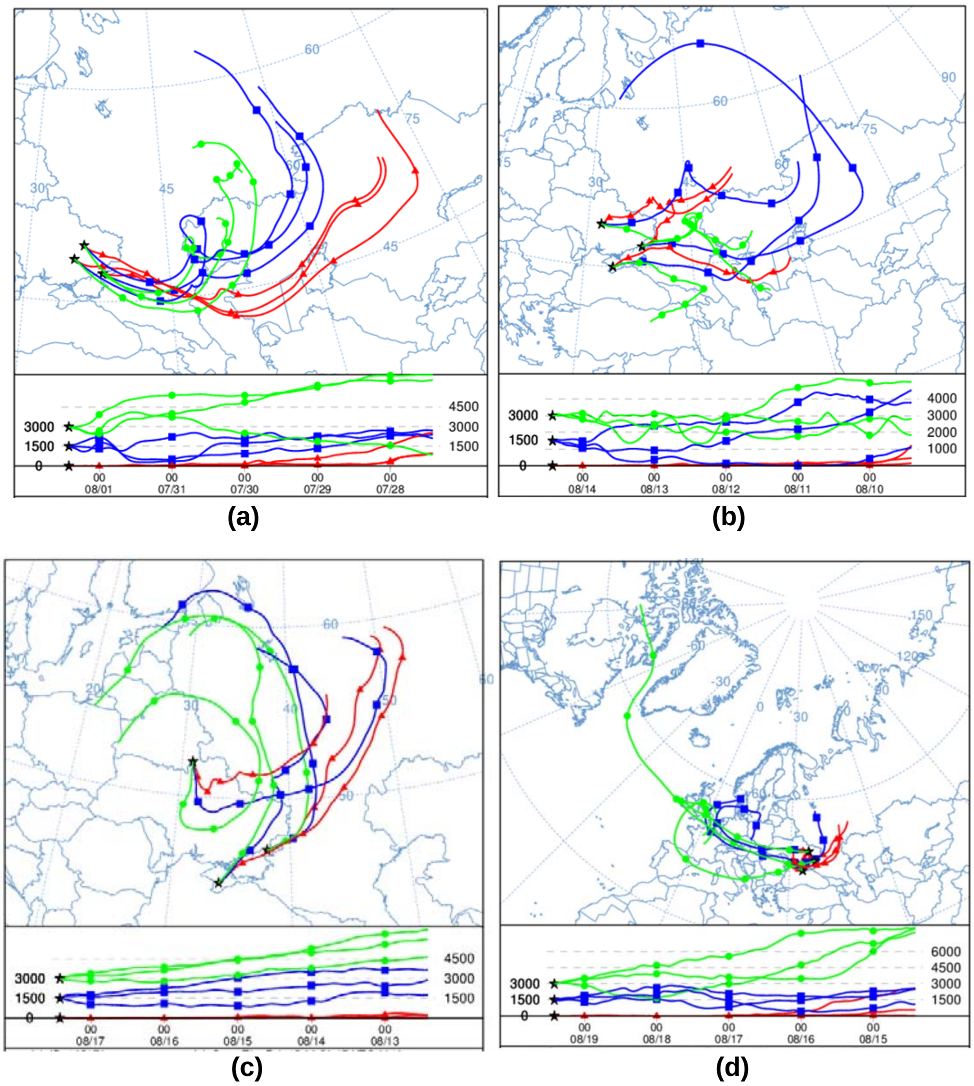
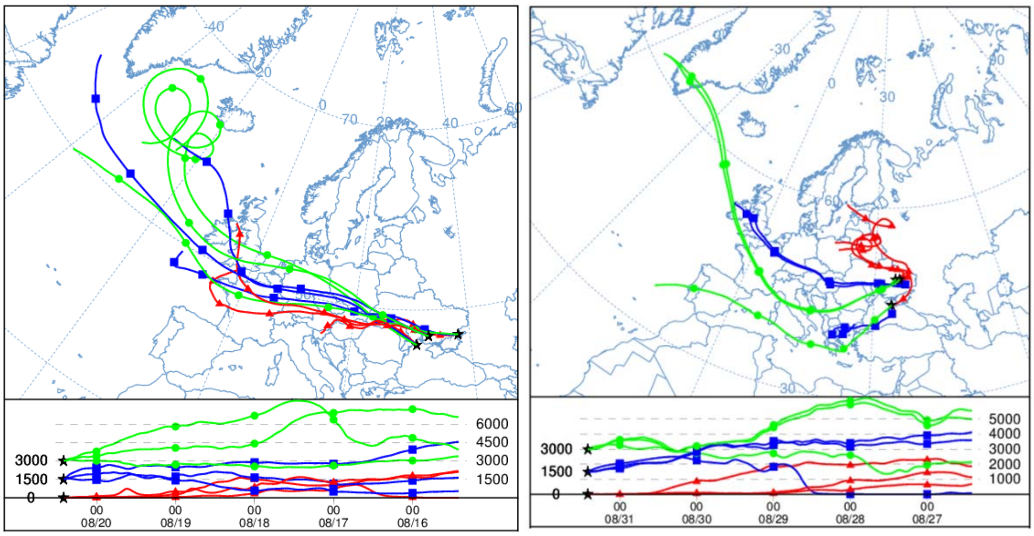


Fig. 8. A backward trajectories ending at 10 UTC: (a) 1 August, (b) 14 August, (c) 17 August, (d) 19 August, 2010 [15]



(a) **(b)**

Fig. 9. A backward trajectories ending at 10 UTC: (a) 20 August, (b) 31 August 2010 [15]

anticyclone over European Russia was dissipated, the baric field was reorganized, and territory of Ukraine was under the influence of the development of western type processes. As can be seen from Figs. 8 and 9, on 17 August and 19 August, the trajectories at the earth`s surface started over the southern and central regions of European Russia (Fig. 8c; d), as a result of the restoration of westerly the air masses caming from regions of Central and Western Europe. After the development of an anticyclone over Central Europe, air masses came from west from Central and Western Europe regions, and the North Atlantic (Fig. 9). During the period 30-31 August, trajectories of air particles started above Western Europe, and subsequently moved through the Mediterranean region. At the earth`s surface, air masses moved from the Baltic Sea area.

4. CONCLUSION

Analysis of this research showed that there is significant spread of dry winds over the territory of Ukraine in first half of August 2010 occurred against the backdrop of the formation, in the European sector, of the meridianal type of atmospheric circulation, with the development of a blocking process over European Russia. This led to formation over European Russia and Ukraine of areas of increased temperature values in the lower troposphere. The development of dry conditions was facilitated by the stable, clear weather, without precipitation, for a long time, as well as the descent of air masses in anticyclone system, leading to their adiabatic heating. Further restructuring of the baric field led to the restoration of the westerly winds above the European sector. The movement of a series of cyclones through to territory of Central Europe led to an intensification of inter-latitude heat and moisture exchange, which contributed to a reduction in the number of dry wind cases in Ukraine. The repeated increase in number of dry winds in the period from 23 August to 27 August occurred on the territory of Ukraine, with a low-gradient baric field of high pressure, which promoted intensive heating of the air on this area.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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